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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Basic criteria for the design of aluminum structures, masonry structures, composite structures and other structural materials (other than steel, concrete and timber) are presented for use by experienced engineers. The contents cover general topics related to these structures, such as connections, bending stresses, crack control, and corrosion problems. A discussion of specific cautions, and special design considerations is included.

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MAY 1980

STRUCTURAL ENGINEERING

ALUMINUM STRUCTURES
MASONRY STRUCTURES
COMPOSITE STRUCTURES
OTHER STRUCTURAL MATERIALS

DESIGN MANUAL 2.6

APPROVED FOR PUBLIC RELEASE

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ABSTRACT

Basic criteria for the design of aluminum structures, masonry structures, composite structures and other structural materials (other than steel, concrete, and timber) are presented for use by experienced engineers. The contents cover general topics related to these structures, such as connections, bending stresses, crack control, and corrosion problems. A discussion of specific cautions, and special design considerations is included.

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FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. This manual uses to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM Headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters, Code 04. As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

D. G. Iselin

D. G. Iselin
Rear Admiral, CEC, U.S. Navy
Commander
Naval Facilities Engineering Command

STRUCTURAL ENGINEERING DESIGN MANUALS

New DM Number	Superseded Chapter in Basic DM	Subject
2.1	-	General Requirements
2.2	1	Loads
2.3	2	Steel Structures
2.4	3	Concrete Structures
2.5	4	Timber Structures
2.6	5, 6, 7, 8	Aluminum Structures Masonry Structures Composite Structures Other Structural Materials
2.7	-	Snow Loads (Tri-Service)

CONTENTS

ALUMINUM, MASONRY, COMPOSITE STRUCTURE, AND OTHER STRUCTURAL MATERIALS

CONTENTS (continued)

CONTENTS (continued)

FIGURES

TABLES

Section 1. SCOPE AND RELATED CRITERIA

1. SCOPE. This manual prescribes criteria for the design of structures (including temporary structures) that are constructed of aluminum, unit masonry, composite construction and other materials in common use for structural purposes. Other materials, for which there are no commonly recognized standards of design (epoxy joints, bamboo reinforced concrete, and adobe are examples) and which, accordingly, are not covered in this manual, may be used for structural purposes under the provisions of Para. 3 of NAVFAC DM-2.1.

2. CANCELLATIONS. This manual, NAVFAC DM-2.6, "Aluminum, Masonry, Composite Structures, and Other Structural Materials," cancels and supersedes chapters 5, 6, 7 and 8 of Structural Engineering, NAVFAC DM-2, of October 1970, and Changes 1 and 2.

3. RELATED CRITERIA. Certain criteria related to the design of aluminum, masonry, and composite structures appear in other manuals in the design manual series and in other sources, as follows:

Subject	Source
General Requirements . . . . Service Classifications and Other General Requirements	NAVFAC DM-2.1
Soil Mechanics, Foundations and Earth Structures . . . . Foundations	NAVFAC DM-7
Fire Protection Engineering . . . . Fire Protection	NAVFAC DM-8
Aluminum Structures	Aluminum Construction Manual, Aluminum Assoc.
Concrete Construction . . . . Masonry Structures	NAVFAC DM-2.4
Fiber Reinforced Concrete . . . . Composite Construction	ACI SP-44
Standard Specifications for Highway Bridges	American Association of State Highway and Transportation Officials (AASHTO)
Manual for Railway Engineering . . . . Bridges	American Railway Engineer Association (AREA)

4. STANDARD SPECIFICATIONS. Throughout this manual, where design criteria are obtained from cited sources, those citations are termed "Standard Specifications."

Section 2. ALUMINUM STRUCTURES

Part 1. GENERAL

1. ACCEPTABLE ALLOYS. See Part 2. DESIGN CRITERIA.

2. CORROSION.

a. General. Aluminum has a higher resistance to corrosion than do the usual alloys of structural steel, but it is not proof against corrosion attacks. In particular, a marine environment is detrimental to some alloys. Care should be exercised when using aluminum under conditions where electrolytic action can develop, as in contact with concrete or with dissimilar metals such as steel.

b. Isolation. Isolate aluminum in applications involving contact with dissimilar metals or with concrete. Isolation shall be achieved by use of coatings specified in the Design Standards listed in Part 2 or by use of materials which have been prequalified by NAVFACENGCOM HQ. Use of stainless steel in contact with aluminum, without isolation, will be permitted.

3. CONNECTIONS.

a. Minimum Connections. There shall be a minimum of two fasteners in any connection (not including pinned or welded connections) except for secondary bracing members such as lacing and battens and except for incidental connections (not including primary bracing members) not proportioned on the basis of calculated stress.

b. Steel Bolts. Stainless steel bolts (and washers) may be used in aluminum structures without precautions for corrosion isolation. Steel bolts (not stainless) may be used if galvanized or cadmium plated. Use galvanized or cadmium plated washers.[1]

c. Eccentricity. Due to lack of yield distortion, effects of eccentricity in connections may not be neglected with aluminum structures.

d. Installation. Use care not to overtorque aluminum bolts. Molybdenum disulfide may be used as a lubricant for threads to minimize torque required.

---

[1] Cadmium plating is not advised for exterior exposures unless the cadmium coating is applied by painting.

4. FIRE PROTECTION. Published fire resistance ratings of aluminum structural elements are unavailable. Except in special circumstances, aluminum should not be used in primary structural elements where fire resistance ratings are required as some alloys start to lose strength at temperatures as low as 200°F.

Part 2. DESIGN CRITERIA

1. CAUTIONS.

a. Modulus of Elasticity. The low modulus of elasticity requires special investigation of deflection, local and overall crippling and buckling situations.

b. Lack of Well-Defined Yield Point. There is no clearly defined yield point. Further, a narrow spread exists between yield and ultimate strengths. Beware of neglect of secondary and parasitic stresses, as such stresses become cumulative with each other and with primary stresses without the relief normally associated with yield of the material. Beware of stress raisers, such as notches. Aluminum tends to tear easily in the presence of such stress raisers.

c. Welding Heat. Welding heat lowers the strength of most aluminum alloys in the heat-affected zone of the weld.

d. Coefficient of Thermal Expansion. The coefficient of thermal expansion of aluminum is about twice that of steel. However, because of a lower modulus of elasticity, stresses in aluminum alloy structures resulting from temperature changes or misalignments of parts often are lower than those in steel structures.

e. Compatibility. Composite action or interaction with steel or concrete framing involves problems of incompatibility because of the difference in coefficients of thermal expansion and modulus of elasticity. In particular, aluminum embedded in, or in contact with, concrete leads to corrosion unless isolation is provided.

f. Use of Aluminum in a Marine Environment. Use caution and consult with NAVFACENGCOM. Certain alloys (principally 5000 series) can give good service, provided that they are of proper temper. Also, if oxygen is precluded from contact with the aluminum (buried, or under plastic washers) accelerated corrosion will occur.

2. SELECTION OF ALLOY.

a. General Characteristics. General characteristics of all aluminum alloys include:

(1) Light weight.
(2) Ease of workability, fabrication, and extrusion.
(3) Corrosion resistance.
(4) Low maintenance cost.

(5) Lack of spark generation (with most materials).
(6) High electrical and heat conductivity.
(7) High reflectivity of light in visible and infrared wavelengths.

b. Structural Alloys. Alloys used for structural applications of aluminum shall be limited to those for which design specifications are available (see Paragraph 3, STANDARDS FOR DESIGN). For comparative characteristics of these alloys, see Table 1 of "Engineering Data for Aluminum Structures," by the Aluminum Association.

3. STANDARDS FOR DESIGN.

a. Class A Structures. Aluminum Association Standard, "Specifications for Aluminum Structures," using allowable stresses for bridge type structures.

b. Class B and C Structures. Aluminum Association Standard, "Specifications for Aluminum Structures," using allowable stresses for building type structures.

Section 3. MASONRY STRUCTURES

Part 1. GENERAL

1. SCOPE. The criteria in this Section apply to unit masonry, utilizing cement and clay and including brick, block, and tile; reinforced and unreinforced; but not to gypsum masonry or plastic components.

2. COMBINATION OF MATERIALS. Allowable stresses as indicated in the referenced Design Standards include consideration of the combination of materials (masonry units and mortar) and are applicable provided that thicknesses of joints are not excessively large.

Part 2. DESIGN CRITERIA

1. DESIGN STANDARDS. The provisions of the Uniform Building Code (UBC) shall apply. For special structures other than buildings, the applicable provisions of the design standard shall be followed. Where seismic design is indicated, the provisions of NAVFAC P-355 shall apply. For walls of hollow, solid, and grouted concrete masonry unit construction, the specifications of the "National Concrete Masonry Association (NCMA)" may be used.

2. CRACK CONTROL--CONCRETE UNIT MASONRY. (See Figures 1-4.)

a. Expansion Joints. Locate to correspond to joints in the structural frame, but not more than 200 ft. spacing.

b. Slip Joints. Slip joints should be provided at exterior corners of masonry walls that support cast-in-place roof or floor slabs. The purpose of the slip joint is to relieve horizontal forces at the corner due to contraction or expansion of the slab or wall.

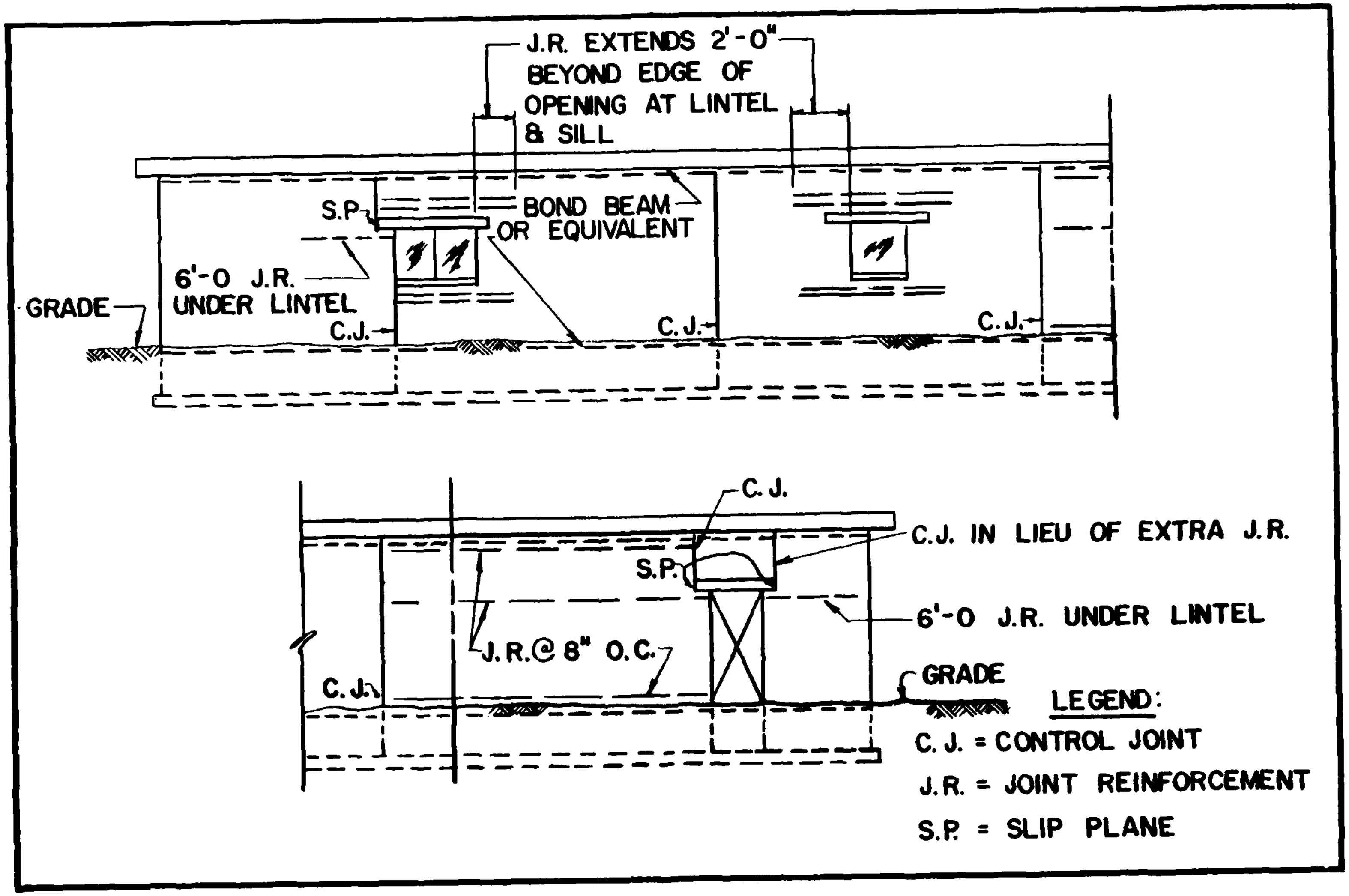


FIGURE 1
Crack Control. Exterior CM Walls (Load-Bearing or Non-Load-Bearing) Using Control Joints and Joint Reinforcement

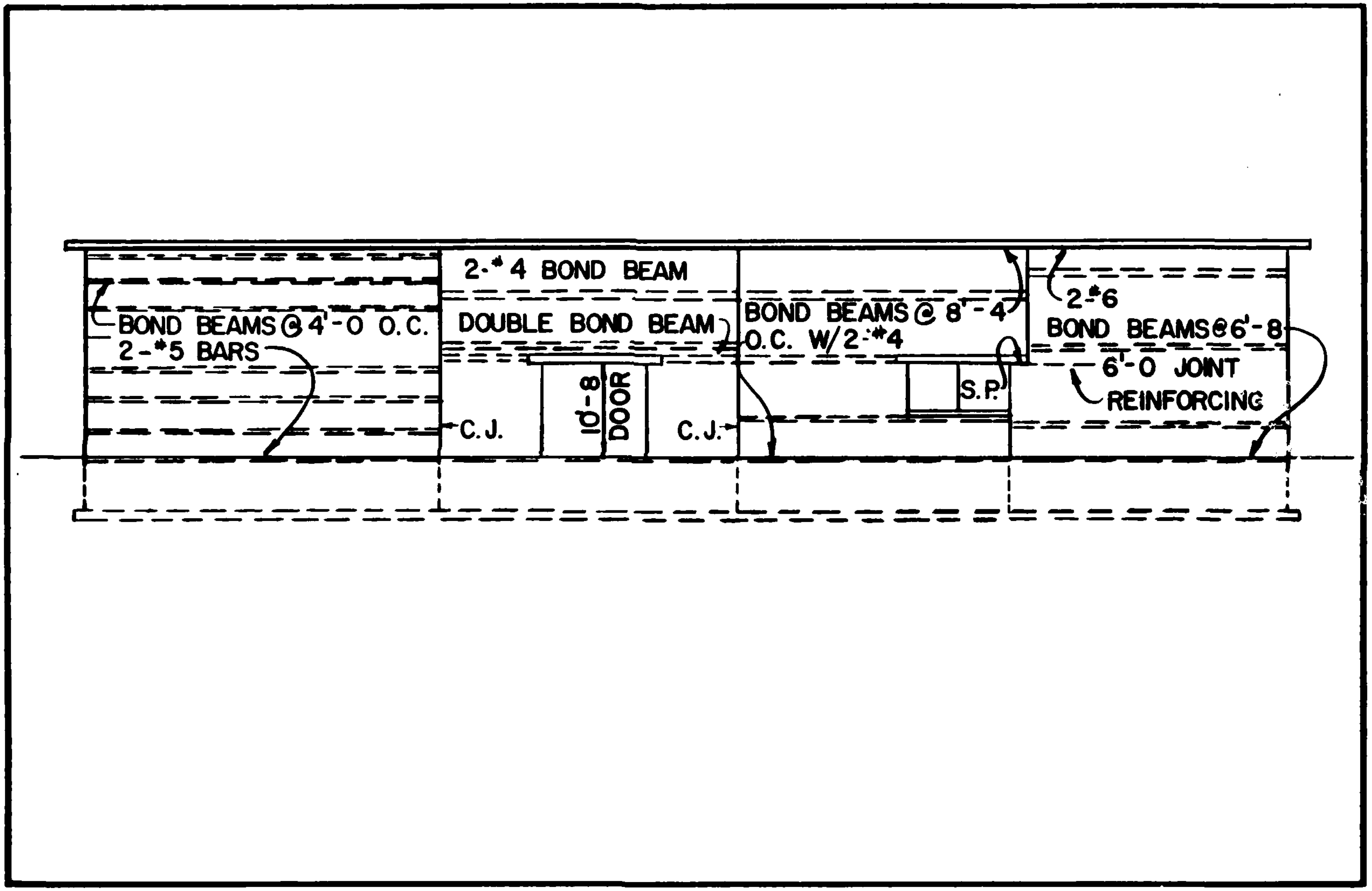


FIGURE 2
Crack Control. Exterior CM Walls Using
Control Joints and Bond Beams

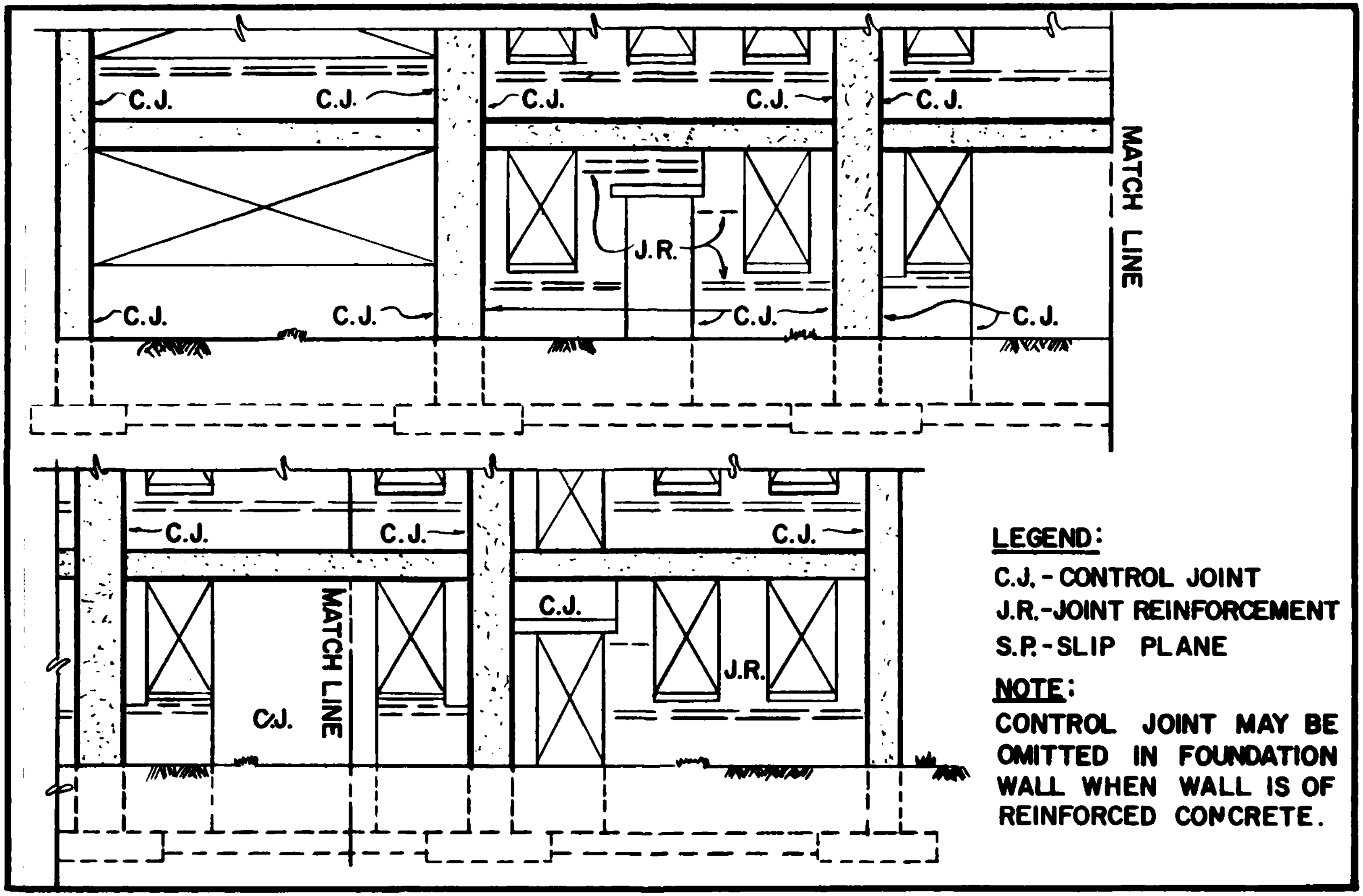


FIGURE 3
Crack Control. Interior Non-Load-Bearing Concrete Masonry Walls Using Control Joints and Joint Reinforcement

c. Load Bearing Walls.

(1) Method A--Control Joints and Joint Reinforcement. All loadbearing concrete masonry walls shall have a bond beam, or its equivalent, located in the first course below the roof framing system, and, in multistory buildings, in the first course of masonry below each floor or deck slab. Walls shall also have control joints and additional horizontal joint reinforcement as designated in Table 1. The values in Table 1 apply to conditions of temperate climate and moderate humidity. The designer may adjust these values for local conditions. The distance between control joints may be increased by 6 feet in humid climates, and it should be diminished by 6 feet in very dry climates. Also, the designer shall give consideration to tensile weakness in the wall caused by large openings. Where heads of openings occur within 2 feet of the roof framing system and/or ceiling height in multistory buildings, a bond beam located at, or immediately above, the lintel can be considered the equivalent of a bond beam at the top of the wall, or at ceiling height. Where the lintel or sill level of an opening falls at other than a bond beam, one of the following measures shall be used:

(a) Locate control joints at both ends of the lintels and sills.

(b) Place joint reinforcement in the two mortar-bed joints immediately above lintel and in the second and third joints below sills, extending from the control joint to a point not less than 2 feet beyond the other jamb.

(c) Locate a control joint at one end of the lintels and sills, and place joint reinforcement in the two mortar-bed joints immediately above the lintel and in the second and third joints below sills, extending from the control joint to a point not less than 2 feet beyond the other jamb.

(2) Method B--Bond Beams in Lieu of Joint Reinforcement.

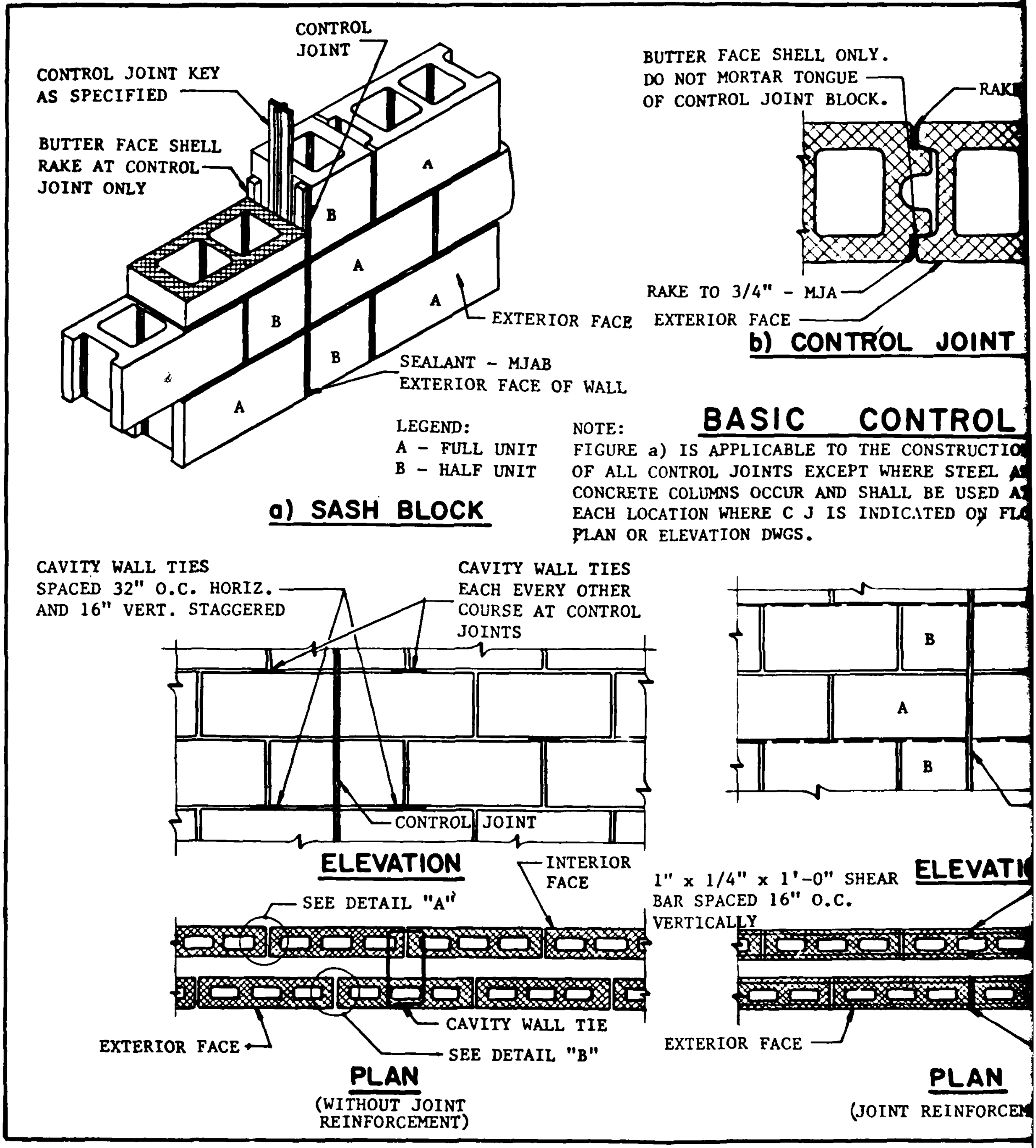
(a) Generally, bond beam reinforcing will consist of two number 4 bars in 8-inch wide bond beams and two number 5 bars in 10- and 12-inch wide bond beams, except as noted in (b).

(b) When the bond beam is used to replace horizontal joint reinforcement, the equivalency is partially determined on the basis of tensile strength. The bond beam spacings equivalent to joint reinforcement at 8-inch and 16-inch vertical spacing are tabulated in Table 2.

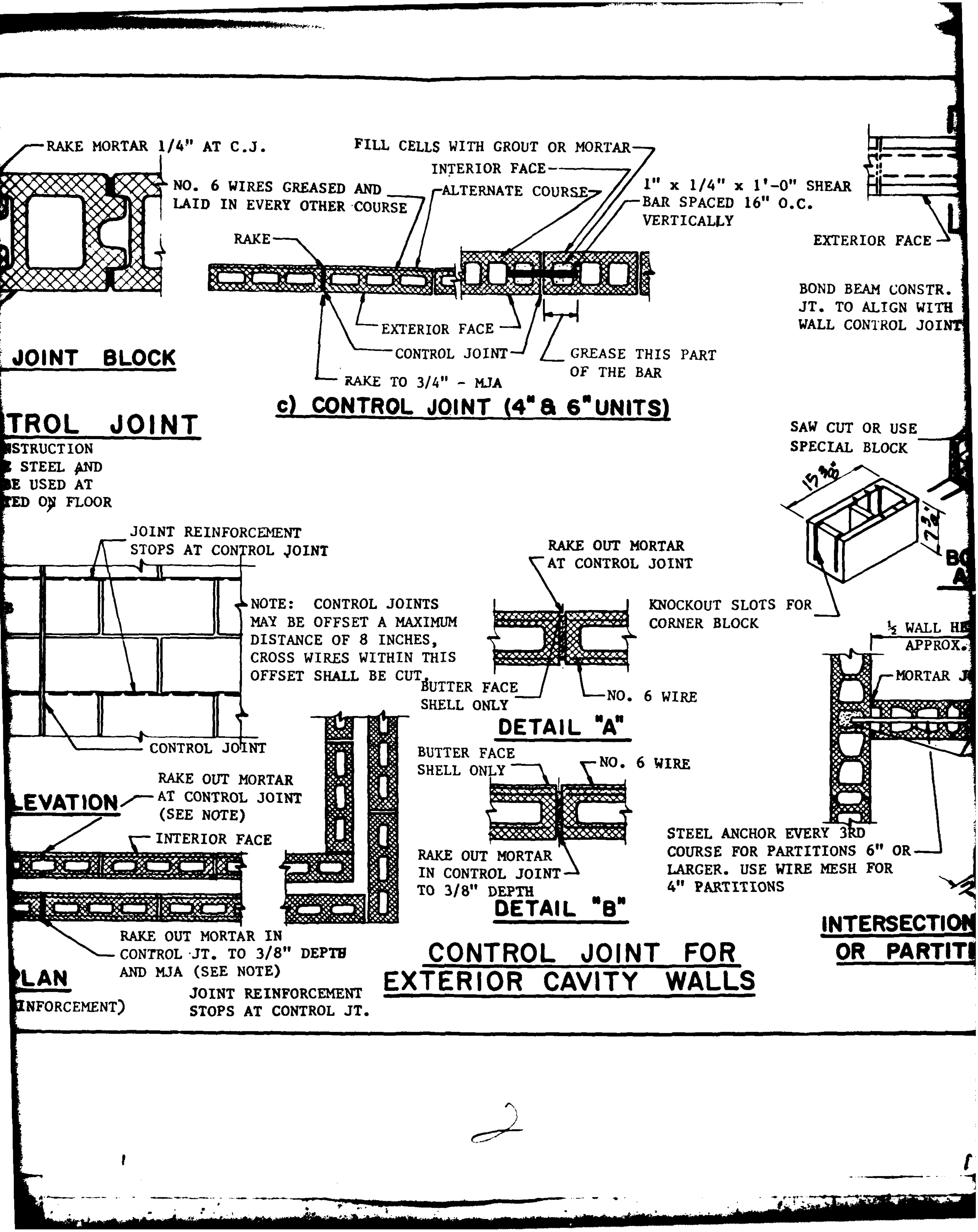
d. Non-Loadbearing Walls. Follow criteria for loadbearing walls, except:

(1) Bond Beams may be located in any one of the top three courses (or 2 feet) below the roof slab or deck.

(2) Curtain Walls or masonry filler walls between columns and beams of concrete or steel frame buildings shall have the same crack control as loadbearing walls, except where exposed frame construction prevents installation of bond beams immediately beneath spandrels. Continuous joint reinforcement may be substituted in three consecutive courses immediately below the interfering structural member.



CONTROL JOINT
CONTROL JOINT KEY AS SPECIFIED
BUTTER FACE SHELL RAKE AT CONTROL JOINT ONLY
A
B
A
A
B
A
B
A
EXTERIOR FACE
SEALANT - MJAB EXTERIOR FACE OF WALL
LEGEND:
A - FULL UNIT
B - HALF UNIT
a) SASH BLOCK
BUTTER FACE SHELL ONLY.
DO NOT MORTAR TONGUE
OF CONTROL JOINT BLOCK.
RAKE TO 3/4" - MJA
EXTERIOR FACE
b) CONTROL JOINT
BASIC CONTROL
NOTE:
FIGURE a) IS APPLICABLE TO THE CONSTRUCTIO
OF ALL CONTROL JOINTS EXCEPT WHERE STEEL
CONCRETE COLUMNS OCCUR AND SHALL BE USED
EACH LOCATION WHERE C J IS INDICATED ON
PLAN OR ELEVATION DWGS.
CAVITY WALL TIES SPACED 32" O.C. HORIZ. AND 16" VERT. STAGGERED
CAVITY WALL TIES EACH EVERY OTHER COURSE AT CONTROL JOINTS
CONTROL JOINT
ELEVATION
SEE DETAIL "A"
INTERIOR FACE
CAVITY WALL TIE
EXTERIOR FACE
SEE DETAIL "B"
PLAN
(WITHOUT JOINT REINFORCEMENT)
B
A
B
1" x 1/4" x 1'-0" SHEAR BAR SPACED 16" O.C. VERTICALLY
EXTERIOR FACE
PLAN



RAKE MORTAR 1/4" AT C.J.
NO. 6 WIRES GREASED AND LAID IN EVERY OTHER COURSE
JOINT BLOCK
TROL JOINT
NSTRUCTION
STEEL AND
E USED AT
TED ON FLOOR
FILL CELLS WITH GROUT OR MORTAR
INTERIOR FACE
ALTERNATE COURSE
1" x 1/4" x 1'-0" SHEAR BAR SPACED 16" O.C. VERTICALLY
RAKE
EXTERIOR FACE
CONTROL JOINT
GREASE THIS PART OF THE BAR
RAKE TO 3/4" - MJA
c) CONTROL JOINT (4" & 6" UNITS)
EXTERIOR FACE
BOND BEAM CONSTR. JT. TO ALIGN WITH WALL CONTROL JOINT
SAW CUT OR USE SPECIAL BLOCK
15 5/8"
7 5/8"
KNOCKOUT SLOTS FOR CORNER BLOCK
JOINT REINFORCEMENT STOPS AT CONTROL JOINT
NOTE: CONTROL JOINTS MAY BE OFFSET A MAXIMUM DISTANCE OF 8 INCHES, CROSS WIRES WITHIN THIS OFFSET SHALL BE CUT.
CONTROL JOINT
LEVATION
RAKE OUT MORTAR AT CONTROL JOINT (SEE NOTE)
INTERIOR FACE
RAKE OUT MORTAR IN CONTROL JT. TO 3/8" DEPTH AND MJA (SEE NOTE)
PLAN
INFORCEMENT)
JOINT REINFORCEMENT STOPS AT CONTROL JT.
RAKE OUT MORTAR AT CONTROL JOINT
BUTTER FACE SHELL ONLY
NO. 6 WIRE
DETAIL "A"
BUTTER FACE SHELL ONLY
NO. 6 WIRE
RAKE OUT MORTAR IN CONTROL JOINT TO 3/8" DEPTH
DETAIL "B"
CONTROL JOINT FOR EXTERIOR CAVITY WALLS
½ WALL HE APPROX.
MORTAR J
STEEL ANCHOR EVERY 3RD COURSE FOR PARTITIONS 6" OR LARGER. USE WIRE MESH FOR 4" PARTITIONS
INTERSECTION OR PARTITI
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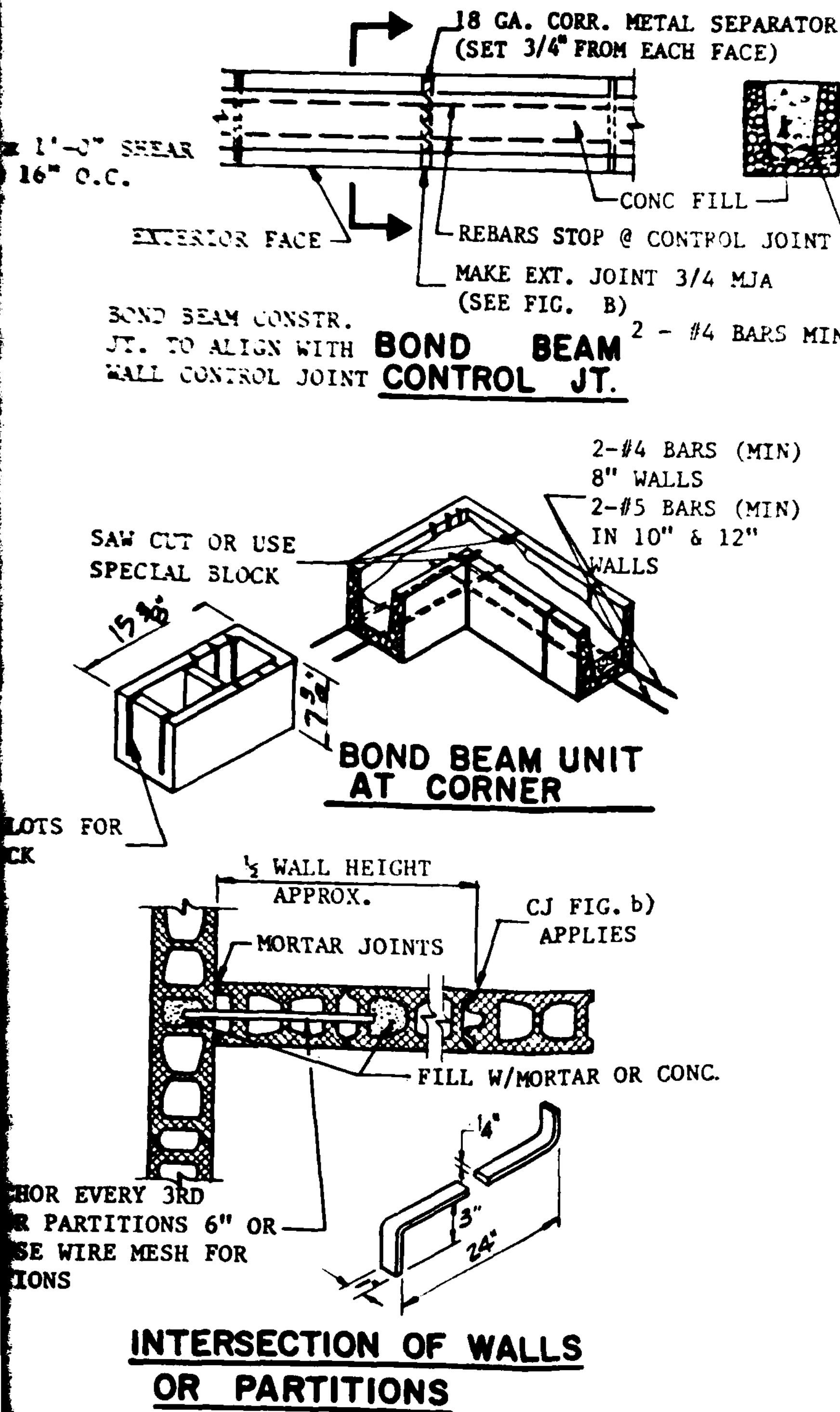


NOTES

1. REINFORCED CONCRETE WALLS BEAMS AND FOUNDATIONS SHALL BE DOWELED AT ALL CORNERS AND INTERSECTIONS BY RIGHT ANGLE DOWELS 2'-0" LONG EACH LEG OUTSIDE FACE ONLY. THE DOWELS SHALL EQUAL THE LONGITUDINAL REINFORCEMENT.

2. WHERE PRECAST CONCRETE OR OTHER LINTELS ARE NOT DETAILED, 8' DEEP BOND BEAM UNITS, OF THICKNESS EQUAL TO THE WALL, SHALL BE USED REINFORCED WITH 2- #4 BARS MIN.

3. KNOCKOUT BLOCK SHOULD NOT BE USED FOR LINTELS.

4. EXCEPT WHERE OFFSETS WITH SLIP JOINTS ARE SHOWN, CONTROL JOINTS IN CONCRETE AND MASONRY SHALL BE A CONTINUOUS VERTICAL LINE FROM TOP OF FOOTING TO TOP OF MASONRY WALL AS INDICATED ON THE BUILDING ELEVATION.

5. ALL JOINT REINFORCING SHALL BE DISCONTINUOUS ACROSS CONTROL JOINTS IN MASONRY.

6. WHERE PARTITIONS EXTEND TO CONCRETE FLOOR OR ROOF DECK ABOVE, AND JOISTS BEAMS OR TRUSSES RUN PERPENDICULAR TO PARTITION, ¼ INCH CLEARANCE SHALL BE PROVIDED AT ALL POINTS BETWEEN PARTITION AND MEMBER. THE ¼ INCH OPENING SHALL BE SEALED.

7. FIG C REQUIRES 6'-0" LENGTH OF JOINT REINFORCEMENT UNDER BEARING BLOCK ON CONTROL JOINT SIDE OF OPENING TO RESIST FRICTION OF THE CONTROL JOINT SLIP PLANE. SLIP PLANE SHALL RETURN OVER TOP OF LINTEL TO ALTERNATE CONTROL JOINT LOCATION IF NECESSARY TO ALIGN WITH JAMB OF OPENING ABOVE.

FIGURE 4
Masonry Details for Crack Control

TABLE 1
Recommended Control Joint Spacing

Vertical Spacing of Joint Reinforcement (inches) (2-No. 9 wires)	Max. Spacing of Control Joints (ft.)*			
	Maximum linear shrinkage potential 0.03%		Maximum linear shrinkage potential 0.065%	
	Exterior Walls	Interior Walls	Exterior Walls	Interior Walls
None	26	30	18	22
16	34	40	24	30
8	40	50	30	38

*Based on moisture-controlled Type I concrete masonry (ASTM C 90, Hollow Load-Bearing Concrete Masonry Units), Type II units, which have no moisture control, shall not be used.

TABLE 2
Bond Beam Equivalence

Equivalent Joint Reinforcing Spacing	Bond Beam Reinforcing and Vertical Spacing*		
	2-#4	2-#5	2-#6
16"	5'-4"	8'-0"	8'-0"
8"	2'-8"	4'-8"	6'-8"

*Cold drawn joint reinforcement wires have a minimum yield strength of 65,000 psi and a working stress of 30,000 psi. ASTM A 615 grade 40 reinforcing steel has a minimum yield point of 40,000 psi and a working stress of 20,000 psi. Because of high bond characteristics, joint reinforcement prevents visible cracks until it yields. The area of a number 9 wire is 0.0173 in. and is 30,000/20,000 more effective than the A 615 steel. The use of bond beams introduces a significant strip of wet concrete in the wall and some wetting of the masonry below the bond beam. For these reasons, the effectiveness calculated below was reduced approximately one-third. On this basis, bond beams with two number 4 bars should be spaced at 32 inches to replace joint reinforcement in every course. Spacing should not exceed 8 ft. 0 in. Therefore, the ratio of effectiveness is calculated as follows:

For 2-#4	.40/2 x 0.0173 x 40/65	= 6.2 times 2/3 =	4 bed joints
2-#5	.62/0.035 x 40/65	= 10.9 times 2/3 =	7 bed joints
2-#6	.88/0.035 x 40/65	= 15.5 times 2/3 =	10 bed joints

(3) Cavity and Veneered Walls. Use the crack control procedures of loadbearing masonry with each wythe of a cavity wall which is constructed entirely of concrete masonry units.

(4) Composite Wall Construction. Where brick and concrete masonry units are used together in composite type walls, the requirements for load bearing masonry apply to the concrete masonry backup. The control joints shall extend through the face brick. (Brick expansion joints extend through backup in composite walls and replace control joints in the same location). The recommended control joint spacing in composite walls is 35 feet for non-reinforced concrete masonry backup. Size and spacing of expansion joints in brick facing and clay tile backup shall be determined by considering expansion due to moisture changes as well as that due to temperature.

(5) Foundation Walls. Reinforced concrete foundation wall control joints shall align with the joints in the masonry wall above. When offsets are required, horizontal slip planes shall be provided.

(6) Parapet Walls. The use of parapet walls is not recommended; however, if used, they shall be treated in the same manner as non-loadbearing walls of the same construction type.

e. <u>Locations of Control Joints</u>. Control joints shall be located:

(1) At wall intersections in L-, T-, or U-shaped buildings, where lengths of wall are such that expansion joints are not required.

(2) At, or near, cross wall intersections, where intersecting walls are 12 ft., or more, in length.

(3) At changes in wall height or thickness.

(4) At both ends of lintels and sills, unless joint reinforcement is provided.

(5) At other points of stress concentration, such as large openings.

f. <u>Details</u>. Control joints shall provide an uninterrupted weak plane for the full height of the wall, including bond beams and foundation walls if constructed of masonry. If the joint is located at a window or wall opening, a horizontal slip plane and extra reinforcement shall be provided under the lintel.

3. CRACK CONTROL--BRICK MASONRY. (See Figure 5.)

a. <u>General</u>. Clay brick or tile masonry walls do not require joint reinforcement or joints for control of cracking because there is no shrinkage due to loss of moisture. The designer shall evaluate the causes of movement in brick walls such as temperature changes and volume changes due to chemical action. The thermal coefficient of expansion for clay or shale brick shall be assumed equal to 0.000004 units per ^{o}F. The design of clay masonry should also provide for a volume change due to moisture expansion that is equal to 0.0002 times the wall length in inches.

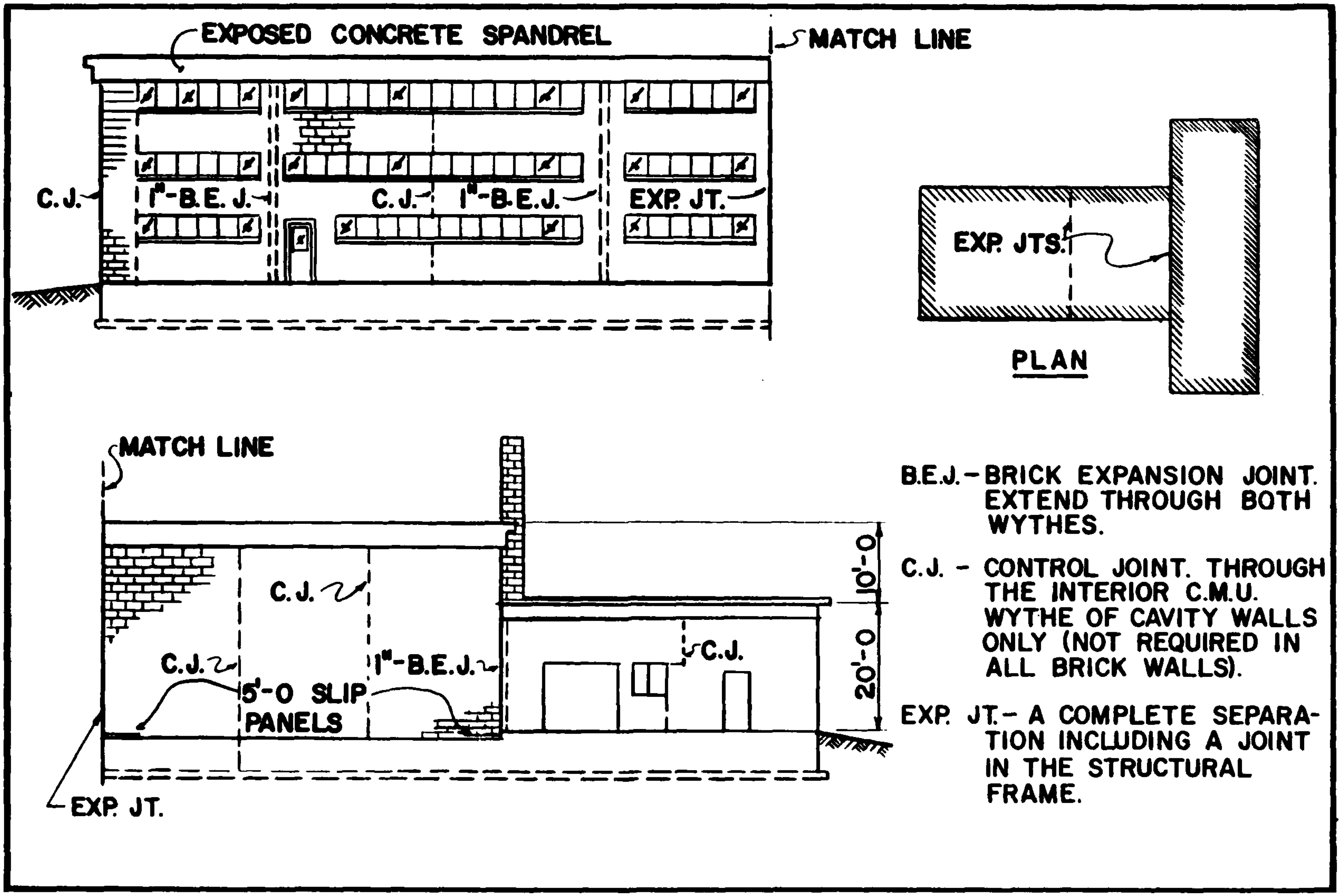


FIGURE 5
Crack Control Methods for Brick Buildings

b. Vertical Expansion Joints. Expansion joints shall be continuous. They shall be filled with sealant to permit partial closure of the joint while absorbing linear growth of the wall. Brick expansion joints are not structural expansion joints. They apply only to the thickness of wall which they protect from expansion, and do not extend through structural floor and roof systems, although they should be located to correspond to structural expansion joints. The overall width of brick expansion joints shall be limited to 1 inch in order to prevent racking damage to doors and windows due to excessive movement. They must be free of extruded mortar and other obstructions. Brick expansion joints are only 50 percent efficient as they cannot completely close because of the sealant within the joint. An accumulated expansion joint width of 1 inch shall be allowed in approximately every 87 linear feet of wall for each 100°F. of temperature differential. Theoretically, the 1-inch width will permit 1/2 inch expansion in the wall. Incremental joints as small as 3/8 inch may be used if architectural considerations dictate. The allowance for expansion and joint spacing shall be adjusted if climatic conditions warrant. Parapet walls require twice as many brick expansion joints as the supporting walls. Brick expansion joints do not transfer shear and must occur at locations where zero bending moment and shear transfer are required.

c. Horizontal Expansion Joints. Brick masonry walls in multistory buildings or in buildings with a large number of openings are often supported on shelf angles at intervals of one or two story levels. Horizontal expansion joints should be placed at shelf angles, especially in concrete frame buildings. These joints should consist of neoprene or similar material immediately below the angles. The joint should be sealed with a mortar-colored elastic sealant. The shelf angles should be secured against any rotation and against deflections over 1/16 inch. Provide a 1/2-inch space between ends of angles for thermal expansion.

d. Composite and Cavity Wall Construction. In cavity wall construction, the requirements for each wythe apply to that wythe, and brick expansion joints and control joints do not necessarily align. In composite wall construction, control joints and expansion joints must extend through the full thickness of the wall wherein either one is required. Brick expansion joints also serve the requirements of control joints. Control joints are not required in clay tile backup walls.

Section 4. COMPOSITE STRUCTURES

Part 1. STEEL-CONCRETE COMPOSITE CONSTRUCTION

1. ACCEPTABLE TYPES OF SHEAR CONNECTORS. See Figure 6. Proposed innovations in type of connectors shall consider separation forces between the composite elements, as well as shear forces. Epoxy bonding will be accepted as providing composite action subject to special review as regards effects of shrinkage, thermal gradients, surface preparation, and delamination of concrete.

2. DESIGN STANDARD FOR CLASS A STRUCTURES. AASHTO Standard, "Standard Specifications for Highway Bridges," shall apply.

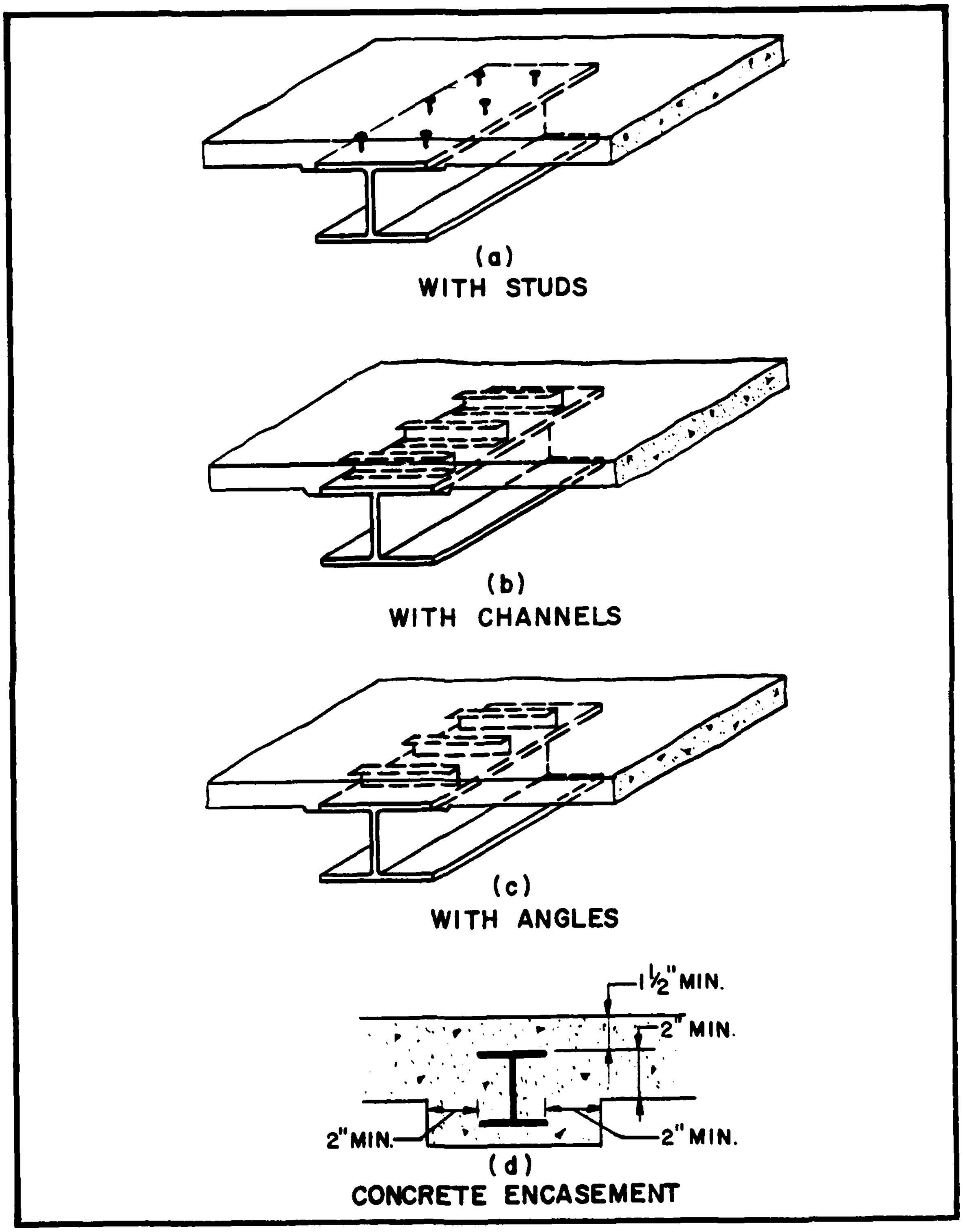


FIGURE 6
Shear Connectors
(Steel-Concrete Composite Construction)

3. DESIGN STANDARD FOR CLASS B AND C STRUCTURES. AISC Standard, "Specifications for the Design, Fabrication and Erection of Structural Steel Buildings" shall apply.

4. SPECIAL DESIGN CONSIDERATIONS.

a. Shrinkage. Steel stresses due to concrete shrinkage are seldom important, but may be checked on the basis of one of the following assumptions, either of which may be used for purposes of computation.

(1) Shrinkage does not cause cracking. In this case, the slab is in tension and the steel stresses may be evaluated by considering the composite cross section as an eccentrically loaded column, with a load of $0.0002E_c nA_c$ applied at the centroid of the slab, where:

A_c = area of concrete flange.
E_c = modulus of elasticity of concrete.
E_s = modulus of elasticity of steel.
$n = E_s/E_c$.

(2) Shrinkage causes cracking of the slab. The total opening of shrinkage cracks is equal to the unit shrinkage multiplied by the length of the beam. To close the cracks, the stress in the top flange of the steel beam must equal the noncomposite dead load stress plus $0.0002E_s$.

b. Expansion. The effects of expansion and differential temperature may be neglected.

Part 2. CONCRETE-CONCRETE COMPOSITE CONSTRUCTION

1. CLASS A STRUCTURES. AASHTO Standard, "Standard Specifications for Highway Bridges," shall apply.

2. CLASS B AND C STRUCTURES. ACI Standard ACI 318, "Building Code Requirements for Reinforced Concrete," shall apply.

3. SEPARATION FORCES. Provide for force which would be required to deflect the deck (slab) units to the maximum deflection curve of the beams.

Part 3. TIMBER-CONCRETE COMPOSITE CONSTRUCTION

1. DESIGN STANDARDS. Except for provisions to provide shear and separation resistance between the two materials, design of the components of timber-concrete composite construction shall be in accordance with the design standards for the timber and for the concrete. Impact shall be considered in evaluating stresses in the concrete, but may be neglected in evaluating stresses in the wood.

2. BENDING STRESSES.

a. Effective Flange Width. The assumed effective width of a concrete slab acting as a T-beam flange shall not exceed any of the following:

(1) One-fourth of the T-beam span.
(2) The distance, center to center of T-beams.
(3) Twelve times the least thickness of the slab.

For beams with a flange on one side of the stem only, the effective flange width may not exceed one-twelfth of the beam span, or one-half of the center-to-center distance to the adjacent beam, or 6 times the least slab thickness.

b. Modulus of Elasticity Ratios. The following modulus of elasticity ratios shall be assumed in determining transformed section properties, where E_c = modulus of elasticity of concrete, E_w = modulus of elasticity of timber, and E_s = modulus of elasticity of reinforcing steel.

(1) T-Beam Design. $E_c/E_w = 1$.

(2) Slab-Deck Design.

$E_c/E_w = 1$ for slab decks in which the net concrete thickness above the wood is less than one-half the overall depth of the composite section.

$E_c/E_w = 2$ for slab decks in which the net concrete thickness above the wood is equal to or greater than one-half the overall depth of the composite section (the use of a net concrete thickness equal to or greater than one-half the overall depth of the composite section has little or no advantage for most highway structures).

$E_s/E_w = 18.75$ for Douglas fir and Southern pine lumber.

c. Joints in Timber Laminations. Laminations in composite slab decks shall be spliced one-third at each quarter-span point, and one-third over the interior supports.

3. DESIGN OF SHEAR CONNECTORS. (See Figure 7.)

a. Type I. Standard plate shear connectors 3-3/4 by 3-1/2 by 3/32 inches. Assume a shear capacity of 1,750 pounds each.

b. Type II. Shear castellations achieved by dapping 50 percent of the top edges to a depth of 1/2 inch. Ends of daps shall be sloped at 30 degrees from the vertical to reduce stress concentrations. Calculate shear capacity based on strength of timber castellations (shear parallel to grain).

c. Spikes to Resist Separation Forces. Provide 60d spikes at 2- to 4-foot center, protruding a minimum of 1-1/4 inches and angled away from the center of span (see Figure 8). Vertical spiral dowels or longitudinal bending grooves may be substituted for spikes.

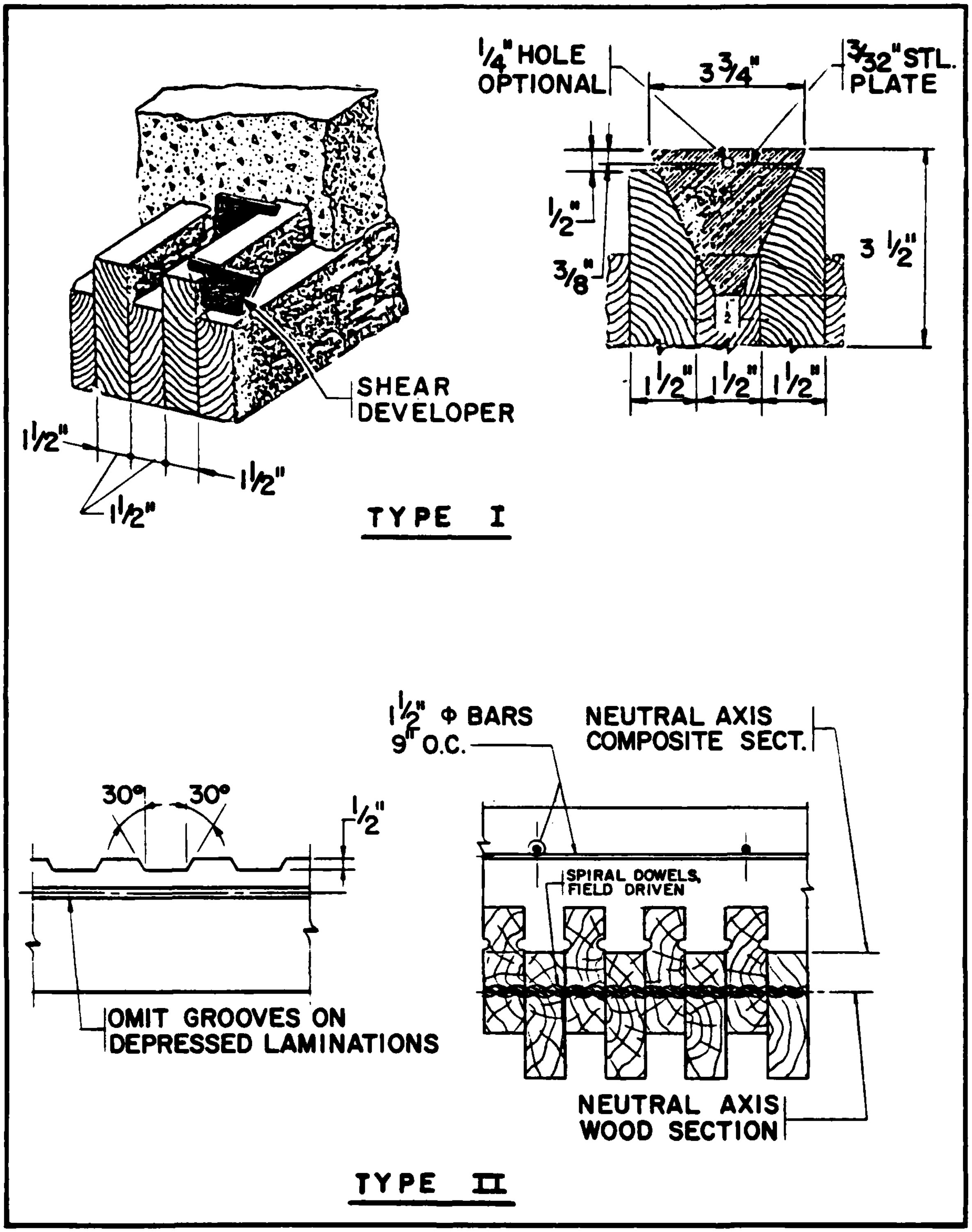
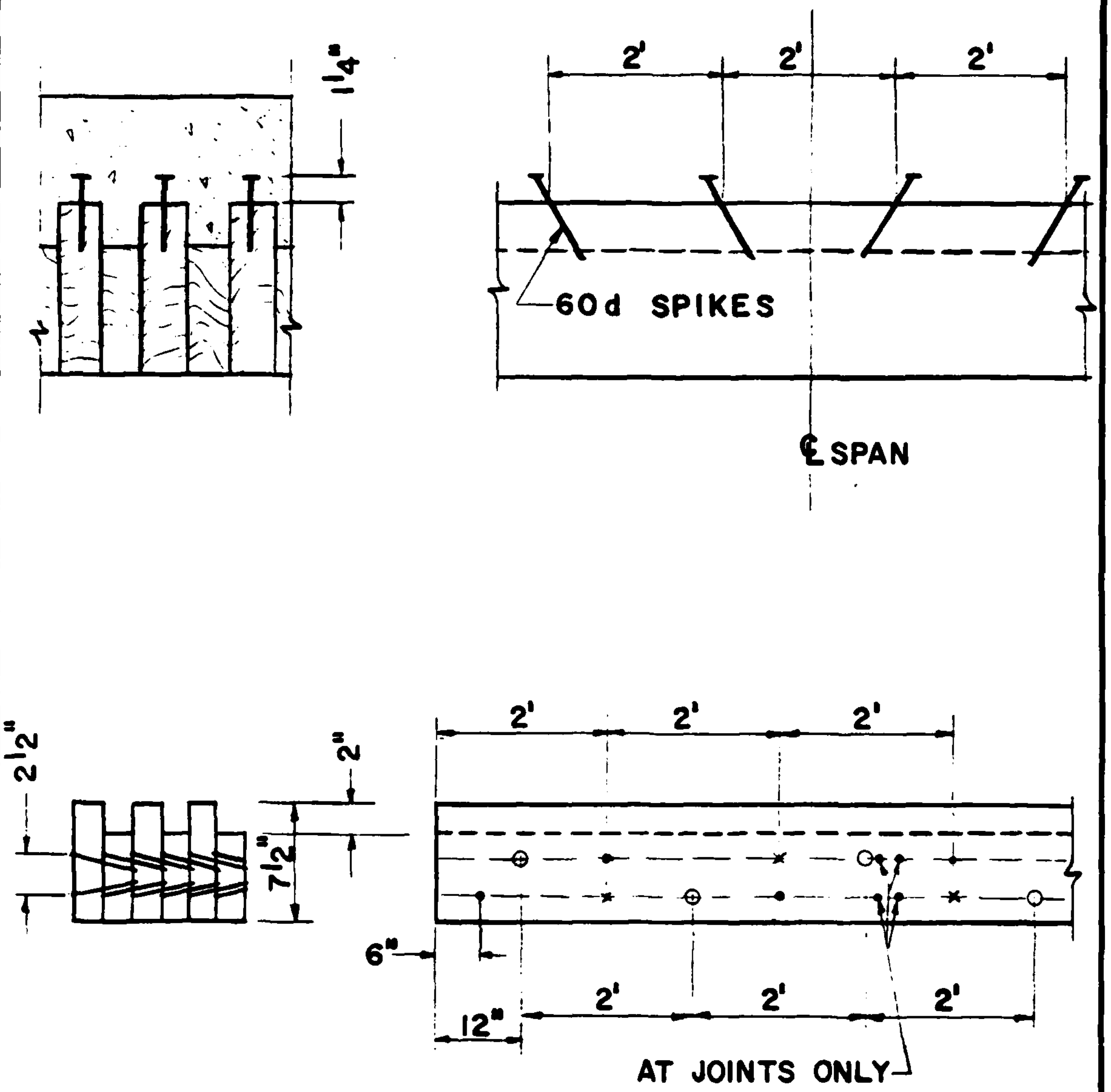


FIGURE 7
Shear Connectors
(Timber-Concrete Composite Construction)



NOTES:

SET NAIL HEADS SO PLANKS FIT TIGHT

× DENOTES NAILS IN FIRST ROW

○ DENOTES NAILS IN SECOND ROW

● DENOTES NAILS IN THIRD ROW

FIGURE 8
Spacing of Uplift Spikes and Nailing

d. Differential Temperature Stresses. Differential temperature stresses are not important, except with regard to shear stresses in Type I connectors. The additional connectors required shall be computed from:

$$N = A_c f_c / S$$

Where: N = number of connectors required for temperature stress (uniformly distributed along beam).

A_c = area of concrete flange considered to be restrained by timber stem (may be assumed as one-third of the total concrete flange area).

f_c = concrete stress induced by differential temperature change.

S = value of each connector.

e. Typical Details. Typical details of timber-concrete composite construction are shown in Figure 7.

Part 4. SANDWICH PANELS

1. FACINGS. Use facings of plywood, aluminum alloy, galvanized or stainless steel, fiberglass, or pressed board. Plywood and pressed board shall not be used for the interior facing of panels unless given a permanent fire-retardant treatment.

2. CORES. Use cores of natural wood such as balsa, expanded fibers, cellular plastics, rubber, mechanically constructed cells or either grid or honeycomb construction, or expanded glass. Where cellular plastics are used, the selection of the specific material shall be made in consultation with the NAVFACENGCOM Engineering Field Division's Fire Protection Engineer, to assure use of a fire safe material.

3. ADHESIVES. Use adhesives to bond facing cores that will provide a bond strength at joints in excess of the strength of the cores.

4. STRENGTH. In flexure, design the core to resist the shear, and the facing to resist the bending moments. Axial compressive loads are limited by buckling, dimpling, or wrinkling of the facing.

Part 5. OTHER STRUCTURAL MATERIALS

1. REINFORCED GYPSUM CONCRETE. Design shall be in accordance with ANSI Standard A59.1, "Specifications for Reinforced Gypsum Concrete."

2. STAINLESS STEEL. Design shall be in accordance with AISI Standard, "Specifications for the Design of Cold-Formed Stainless Steel Structural Members."

S. I. Conversion Units

The following metric equivalences were developed in accordance with ASTM E 621 and are listed in the sequence as they appear in the text. All equivalences are approximate.

200° F	=	93.5° C
200 feet	=	60 m
6 feet	=	1800 mm
2 feet	=	600 mm
35 feet	=	10.5 m
12 feet	=	3.5 m
.000004 units/°F	=	.000007 units/° C
±87 feet/100° F	=	±15 m/100° C
1 inch	=	25 mm
1/2 inch	=	13 mm
3/8 inch	=	10 mm
1/16 inch	=	2 mm
3 3/4" x 3 1/2" x 3/32"	=	95 mm x 89 mm x 2.4 mm
1750 lbs.	=	794 kg.
1/2 inch	=	13 mm
1 1/4 inch	=	32 mm
2 ft. to 4 ft.	=	600 mm to 1200 mm

REFERENCES

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Aluminum Construction Manual
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AASHTO Standards. American Association of State Highway and Transportation Officials, Washington, D.C. 20004
Standard Specifications for Highway Bridges

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ACI-318. Building Code Requirements for Reinforced Concrete
ACI SP-44. Fiber Reinforced Concrete
State of the Art Report on Fiber Reinforced Concrete

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Specification for the Design, Fabrication and Erection of Structural Steel Buildings

AISI publications. American Iron and Steel Institute, New York, New York 10017
Specifications for the Design of Cold-Formed Stainless Steel Structural Members

ANSI Standards. American National Standards Institute, New York, New York 10018
ANSI Standard A59.1. Specifications for Reinforced Gypsum Concrete

ASTM publications. American Society for Testing and Materials, Philadelphia, Pennsylvania 19103
ASTM C 90. Hollow Load-Bearing Concrete Masonry Units
ASTM E 380. Standard Metric Practice Guide

Department of the Army, Washington, D.C. 20315
Army TM 5-809-3 and Air Force AFM 88-3. Masonry Structural Design for Buildings

NAVFAC Documents and Standards. Government agencies may obtain documents from the U.S. Naval Publications and Forms Center, Philadelphia, Pennsylvania 19120. Telephone number: AUTOVON-442-3321; commercial 215-697-3321. Non-government agencies may obtain documents from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
NAVFAC DM-2.1 General Requirements. Structural Engineering
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Specification for the Design and Construction of Loadbearing Concrete Masonry

RS-222. Electronics Industries Association

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